How Can Neuroimaging Inform Our Treatment of Reading Disorders in Children With Learning Disabilities?

By Joseph Rueter

Submitted in partial fulfillment of the requirements of the Master of Arts Special Education degree at the University of Alaska Southeast

Joseph Rueter
EDSE 692 Special Education Seminar
Title: How can neuroimaging inform our treatment of reading disorders in children with learning disabilities?

Abstract

Neuroimaging technology in the last two decades has allowed a direct 3 dimensional view of the processing activity in an individual's brain while completing a particular cognitive task enabling the characterization of functional brain areas and typical processing pathways. This meta-synthesis examines current studies of the neuroimaging of reading in both typical proficient readers, and individuals with developmental dyslexia and examines how these studies can inform our treatment of reading disorders. Functional Imaging studies with fMRI, DTI, MEG, and EEG techniques have documented that the brains of individuals with dyslexia have distinct physical differences and an atypical processing of reading tasks when compared to their normal reading peers. These differences in both form and function can be determined in young pre-reading age children, enabling the early identification (with 90% accuracy) of individuals that will later struggle with the disability. Researchers in the field indicate that DD is an evolving progressive disorder beginning with a distinct phonological disorder and evolves into semantic word recognition disorder as the child ages. The underlying causes for DD that are being currently advocated are a Magnocellular/vision deficit, a cerebellar deficit, and/or a phonological deficit. Studies indicate that more than one of these deficits may be contributing factors, however 90% of individuals presenting with the DD have a phonological deficit as a major contributor making this the target area of most early interventions. Many studies have contrasted the functional scans of DD readers before, and after phonological interventions in an attempt to characterize a neuro-plastic change resulting from the intervention. These contrast studies indicate that many individuals with dyslexia will normalize their atypical processing of written information to appear to process written text much like their proficient reading peers. However, there are still many individuals with dyslexia who do not respond to interventions with normalization, but instead compensate for their atypical processing of written text by recruiting disparate areas in the brain to accomplish the same task. These researchers' results indicate central challenge of developing interventions guided by the neurology. These interventions should target activation of a given brain system identified to be the source of the deficit in an individual's Dyslexia with the intent to induce a neuro plastic, normalizing change in brain.

1.0 Introduction

1.1 Background

Students with Specific Learning Disabilities (SLD) are the most populace category of the different categorical disabilities covered under the Individuals with Disabilities Education Act (Disability Compendium, 2014). However, a learning disability is a cognitive disability and as such is not readily apparent. A child cannot just be physically examined and be diagnosed based on physical symptoms. It is a disorder of thinking, reasoning, remembering and or processing information. It is no wonder that professionals have disagreed over a definition for qualifying students for this category of disability (Smith, 2012)

Much of the current definition of SLD defines it by saying what it is not: From the 2006 Code of Federal Regulations (CFR) a Specific Learning Disability (SLD) is not a learning problem caused by a: visual, hearing, or motor disability, or Intellectual disability, emotional disturbance, or of environmental, cultural or economic disadvantage (Smith, 2012). All these other possible explanations for a child's underperformance should be eliminated when considering classification under SLD. The 2006 CRF goes on to define it as a disorder in one or more of the basic psychological processes involved in understanding, using language spoken or written, that manifests as an underperformance in listening, thinking, speaking, reading, writing, spelling, or doing mathematical calculations. It can include perceptual disabilities, brain injury, dyslexia, and developmental aphasia (a language disorder that develops in a previously normal individual as a result of injury or illness (Smith, 2012).

Dyslexia, synonymous with "specific reading disability", is a language based learning disability that is characterized by a cluster of symptoms which result in people having a difficulty with language skills and most specifically reading. Of the 6-7% of all children who qualify for special education under IDEA as SLD; around 85% of those have a primary learning disability in reading and language. Aside from these figures the International Dyslexia Association estimates that 15-20% of the population as a whole have some of the symptoms of Dyslexia (IDA, 2012). The exact causes of dyslexia are still being studied. Researchers conducting brain imaging studies are showing us that the way the brain processes written and language information in children with dyslexia is different than in their non-disabled peers.

The ability to read is not like language which is an inherent evolved trait that is passed on genetically. Language abilities have areas of the brain preprogrammed from birth to facilitate the development of this trait. Reading however is a learned skill which recruits various areas of the brain to accomplish. Many of these recruited areas evolved for other reasons but are recycled so to speak into the reading circuitry that each of us fashions as we learn this skill. Dehaney coined the term "neuronal recycling” to describe both reading and similarly other learned skills that may borrow and incorporate neuronal tissue that originally evolved for some ancient purpose, into accomplishing a more useful task in the present cultural context (Dehaney, 2009)

Individuals with dyslexia do not lack intelligence or desire to learn. They are extremely challenged with identifying the separate speech sounds with in a word (phonology), and working with letters to represent those sounds in reading. Teaching within these student’s strongest modalities can lead to significant progress in reading performance. Interventions have been developed that show improvement in the measured reading performance standards (behavior) of many individuals with dyslexia this improvement in reading behavior however, may be a result of an atypical and inefficient neural processing mechanism when compared to the brains of proficient readers (Temple, 2003). Interventions are needed to target the improvement of both deficits in reading behaviors, but also the inefficient and atypical neural processing pathways of language and written information characteristic of individuals with dyslexia Barquero, Davis, & Cutting, (2014).

Neuroimaging

Current brain research provides increasingly detailed information on how reading is accomplished by both the brains of proficient and dyslexic readers through the use of “functional neuroimaging studies” (Dehaene, 2009). Functional neuroimaging is the use of neuroimaging technology to measure an aspect of brain function, often with a view to understanding the relationship between activity in certain brain areas and specific mental functions in this case reading tasks. It is primarily used as a research tool in cognitive neuroscience and neuropsychology.

Two common methods to image brain activity or activation are positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). When an area of the brain is actively processing a task, energy is consumed and blood flow increases into that area. Both PET and fMRI measure activation in the brain by measuring changes in blood flow into these areas. (PET) involves introducing a radioactive tracer into the blood just before imaging and imaging changes in blood flow to active areas by imaging the change in the presence of the radioactive compound in those areas of the brain. (fMRI) is able to image brain activation by tracking changes in the iron containing compound hemoglobin present in blood which is sensitive to the magnetic field changes induced in MRI.

Another method, multichannel electroencephalography (EEG) event related potentials (ERP's) measured at the surface of the skin of the head by attached electrodes. ERPs and their magnitude relate to brain activity just below the surface in the brain and can be used to image which areas of the brain are working to accomplish a particular cognitive task with precise timing. ERP measurements are very economical relative to the high cost of both MRI and Pet scans. However, EEG data is much less specific with regard to areas of activation. The information basis for images from a PET or fMRI scan is the 3 dimensional "voxel". The Voxel is the 3 dimensional equivalent to the 2 dimensional "pixel". Magnetoencephalography (MEG) can image activation in the brain by sensing the small changes in magnetic field caused be nervous impulse in brain tissue. Like EEG it is an actual real time measure of activity rather than an analog of brain activity like blood flow in fMRI (Eberhard-Moscicka, Jost, Raith, Maurer, et al., 2015).

Neuroimaging technology in the last two decades has allowed us a direct 3 dimensional view of the processing activity in an individual's brain while completing a particular task. It allows us to see where and when that processing takes place in the brain of a subject, relative to the cognitive task that individual is performing at the time of the scan.

Diffusion Tensor Imaging DTI is a method that allows the imaging of pathways of information transfer in the white matter of the brain. White matter is essentially the "computer bus" of the brain allowing quick transfer of information between specialized processing areas. DTI generates information about brain structure based on the diffusion of water molecules within brain tissue in the presence of a strong magnetic field. In the grey matter or cerebrospinal fluid, diffusion tends to occur in all directions, however in the myelinated nerve fibers of white matter it tends along the length of the fibers. This diffusion tendency information can be computed for individual voxels produced in a DTI scan. The physical directional tendencies of white matter tracts in the brain follow these diffusion tendencies and allow elaborate and detailed images of the interconnections in the brain. This technology allows us to verify remotely the interconnecting pathways between different processing centers of the brain.

These techniques together have allowed us to characterize the typical pathways of information transfer along with where that information is being processed in typical proficient readers. Fascinating is that individuals the world over, speaking different languages, and using alphabets with varying orthographies seem to recruit very similar brain areas and pathways to efficiently accomplish reading (Wolf, 2007). However, researchers also found in these studies individuals with dyslexia who often have adopted an atypical neuronal mechanism and pathway to process the same reading tasks.

Why these atypical brains get wired this way as well as what can be done in terms of intervention to produce more typical efficient neural pathways for reading is the interest of this paper. Neuroimaging studies of the brain regions involved in reading have the potential to be used in latitudinal studies with children with dyslexia to show us which instructional methods and interventions give us both improved reading behavior, and the necessary underlying improvements in neural processing of written information that will lead to a long term improvement in the trajectory of dyslexic readers (Barquero, 2013).

1.2. Author's experiences and beliefs

I began my fascination with how children learn to read through my own experiences with my own children. I am a father of 2 children ages 12 and 16. I had the opportunity to give up my job and be a stay at home parent when my children were young, seized the opportunity and have not looked back. I became involved with the governance of their Montessori Preschool Kindergarten and participated as a volunteer in the school's early readers program. I worked with 3, 4, and 5 year olds advanced for their age in reading. My role was to listen to them read and encourage their interest.

The diversity of ability in reading at this early age struck me. My own oldest child, Gabe, extremely precocious in his language skills, had no interest in reading until mid-way through first grade. He did love to be "read to" however, and would sit for hours and listen to books and novels that we as a family read each evening. After consuming the Harry Potter series as a family when he was 5, it became apparent that it was always the parent readers that had to put an end to the evening's readings. It was this parental limitation to his insatiable desire to be read to that I believe finally propelled him to independence in reading mid-way through his first grade year. We then had to monitor him because he often seemed like he wasn't sleeping. We soon found the headlamp under the pillow one day and clearly understood his self-inflicted insomnia.

My daughter had it easy having watched her brother. Her ascendance to "bookworm girl" was a steady climb that progressed into chapter books in first grade and novels in second grade. Unlike her brother who enjoyed being read to, she had an eye in the book early and was always attempting to turn the page when I was midway through reading it out loud. She now even more than her brother is a prolific consumer of written material. I routinely return her to the library with a 1 foot stack of books that she has knocked off that week. 300 page single sitting reads are not uncommon. She at 12 has far exceeded both her mother and fathers reading rate.

As my children have gotten older I have gravitated to the elementary schools for work, first for 3 years as an Early Math Initiative tutor, and for the last 4 years as a special education aid teaching young children k-4th grade to read. I have worked with a variety of wonderful, interesting kids in this capacity. None of these kids have puzzled me more than those that have qualified under the designation of learning disabled.

"You can feel the frustration rise to the surface as she tries, really tries, to see what the others are seeing in the text. Leaning forward putting the index fingers of both hands on either side of the word, pointing to it. She seems to be taking one of the techniques I have given her to improve her reading, that of pointing to the word she is presently decoding, and, by using both hands, both fingers, doubling that effort. She starts articulating it with the last letter of the word then stops, restarts on the left hand side of the word and gradually picks out some of the letter combinations that we have been reviewing and practicing, then blurts out the word without the suffix, without actually having fully decoded the entire string of characters. But we celebrate! Then review the sound correspondence for each letter and letter combination (she knows them all), and go on to the next challenge…. that is adjacent…on the same line of text”.

I work with a number of children like this young girl each day. I admire the amount of pure effort they put into attempting to decode written text. I praise their incremental progress, celebrate the small gains that we get to see together. Theirs however is truly “the longest row to hoe” in comparison to their reading proficient peers in the classroom. I often reflect on my own children’s seemingly effortless accomplishment of reading and have nothing but admiration for the persistence of these children’s day to day efforts with reading. By 4th grade, the general education expectations are that they will be reading proficiently and are “reading to learn”, not still “learning to read”. Children who are not yet proficient readers in 4th grade are doomed to falling behind in the regular classroom without extensive supports and/or assistive technology.

I am learning in my studies on children with reading difficulties that there are many reasons that a child may have difficulty learning to read. They may lack the cultural familiarity to understand what they are reading. They may lack the foundation of having been read to as a child, and as such lack the familiarity with the language used in books, as well as the motivation. They may have a specific learning disability that involves a difference in the way they process visual and phonological information, the integration of which is essential in the reading process. This last example is what is commonly referred to as developmental dyslexia. Interesting to me is the caution with which this term is wielded in the schools in which I work.

My experience has been that there seems to be a distinct aversion to approaching reading disability with a more discreet evaluation, looking for where in the complicated learning process things have or are going wrong. However the rapid depth of neurological understanding of how the brain accomplishes reading and reading disorders that has occurred as a result of neuroimaging demands our attention and application in our treatment of reading disorders.

It must be said that the author is a scientist and soon to be certified special education teacher. I have published papers in both engineering and chemistry journals. I however, have no specialization in the field of neurology to which most of these peer reviewed studies pertain. In this meta-synthesis I have tried to glean the pedagogical implications of studies in peer reviewed papers written mainly for the neurology field. I ask that my work be viewed in that context. I have attempted to pull together common themes and findings that apply directly to the successful education of children with learning disabilities.

My belief is that we will soon have a very refined look at the neural networks cast by our brains as they learn to read. Early detection of the atypical neural processing characteristic of dyslexia will soon become widespread. This information will allow us to develop refined interventions that will change the way readers with disabilities cast those neural nets during learning so that their brains are essentially developed through tuned experience to function more efficiently in reading like their nondisabled peers.

I have heard it said that “a learning disability is not something that you fix, but something you learn to live with”. I believe that soon we will be able to actually physically fix some of the processing deficits in the brain associated with specific reading disability or Dyslexia.

Section 1.3 Purpose

My purpose for this paper is investigate how neurology and most specific, neuroimaging, can inform our treatment of reading disorders in children with learning disabilities.

I will examine the literature to:

First, explore current studies in the neurology and neuroimaging of reading that characterize the current understanding of the normal reading mechanism that is developed by proficient readers.

Secondly, to look at Neuroimaging studies that characterize the neurology of individuals with dyslexia in comparison to their normal proficient reading peers.

Then thirdly, establish what current research indicates are interventions and teaching methodologies that produce measurable positive impacts on the way the brains of these individuals process reading tasks. This implies that not only are behavioral measures used to validate these effective interventions (standardized, or diagnostic testing) but also Neuroimaging or some other direct measurement of neurological activity can demonstrates positive impacts of the intervention.

Lastly I wish to glean from these expensive and academic works on the neurology of reading what hope we may have of in the near future of developing a protocol of diagnostics and early intervention to normalize the atypical brain processing that cripples the reading ability of individuals with dyslexia.

2. Methods

Selection Criteria

The journal articles included in this paper were selected based on the following search criteria:

1. The article explores dyslexia from both a behavioral perspective, and the underlying neurology by way of neuroimaging or other technique.
2. The article discussed a study that had implications for the design or implementation of effective interventions for dyslexia
3. The article explored the underlying differences in the ways that individuals with dyslexia process written information versus their nondisabled peers.
4. The article was published in a peer reviewed journals related to education and, or science.
5. The articles were published after 2003 to 2015.

2.2 Search Procedures

Data Base searches and ancestral searches were used to find articles that fit the above search criteria. I also found that by using a “cross referenced listing” from relevant and recent studies I found in database searches, I was able to get up to present date published research articles not revealed in those initial data base searches. This may be due to the recent rapid advances in this area. The website that provided this service was the website for the Proceedings of the National Academy of Science (http://www.pnas.org). Using this method, a particularly good source could not only be a potential ancestral search candidate, but also a great point to find just recently published material that is continuing on in the same research strand.

Section 2.2.1 Data Base searches

Searches for articles that conformed to the search criteria were done on Educational Resources Information Center (ERIC), Science Direct and Google Docs. I used the following Boolean search terms:

"Neuroimaging And Developmental Dyslexia"

"Neuroimaging And Reading"

"Neuroimaging And Reading Intervention"

"Reading and Brain Research"

Additionally I used the "cross-ref" option of the Proceedings of the National Academy of Sciences website with Temple's 2003 landmark article, "Neural deficits in children with dyslexia ameliorated by behavioral remediation: Evidence from functional MRI." This yielded amongst others my most current resources for this paper: Ylinen & Kujala, 2015; Barquero, Davis & Cutting, 2014; Pammer, 2014; and Waldie et al., 2013.

Section 2.2.2 Ancestral searches

An ancestral search makes use of an in hand articles reference list as a source of additional studies that satisfy the selection criteria of the current study. I did an ancestral search on the bibliography of Barquero, Davis & Cutting's 2014 PloS one article, "Neuroimaging of reading intervention: a systematic review and activation likelihood estimate meta-analysis". This yielded 3 articles: Lovio et al. 2012; Krafnick, Flowers, Napoliello, Edenet, 2011; and Yamada et al., 2011 that met my search criteria.

Section 2.3 Coding procedures

I used two tables to code the information in the 32 articles reviewed for this paper. Table 1 classifies all the articles used in my paper by publication type (detailed below in section2.3.1). Table two is restricted to research studies and codes them by Research Design (see section 2.3.2), Study Participants, Data Sources, and Findings of the research.

Section 2.3.1 Publication types

Each publication used in this paper was categorized in Table 1 by publication type: *research study, theoretical work, descriptive work, position/opinion paper, guide, annotated bibliography, or review of the literature*. *Research studies* describe in detail there design and procedure and produce well documented qualitative or quantitative data on which discussion and conclusions are based. *Theoretical Works* explain or expand current theories or theoretical models that define the paradigms of scientific inquiry and understanding. *Descriptive works* describe experiences and phenomena but do not give detailed information on methods used to gather data. *Position/opinion papers* argue for a particular policy, theory or approach to a subject. *Guides* describe how a particular program, or approach base on a theoretical model might be implemented. *An annotated bibliography* is a listing of sources concerning a particular topic with a brief review critiquing the significance of each. *A review of the literature* is a piece that looks at relevant work on a particular topic and attempts to summarize and put together topics themes and conclusions that predominate in the articles identified (Duke, 2011)

Section 2.3.2 Research design

The research articles used in this paper were classified according to research design used. Quantitative works are based on numerical measures in the results of the study and any conclusions will have numerical values supporting the findings. Qualitative works will be based on a study that will use words and language to convey degrees of elements being studied. Mixed methods use both qualitative and quantitative work as a basis of the findings of a study.

Most of the studies were quantitative studies based on a measured spatial activation of brain tissue during reading tasks or intervention as measured by fMIR, and behavioral measures of reading performance. However a number of the studies made attempts to pool general findings from a group of similar studies and were more qualitative in nature. Still others were of the mixed of both qualitative and quantitative measures. For example Barquero, Davis and Cutting's 2014 article is an example of one of these mixed methods studies that has both done a pooling and reanalysis of the quantitative data from a number of intervention fMRI studies, as well as using qualitative information from a number of other studies in the presented results (Barquero, Davis, & Cutting, 2014).

Section 2.4 Data Analysis

Table 1

Authors	Publication type
Barquero, Davis, & Cutting, 2014	Literature Review
Brem, et al., 2009	Research Study
Costanzo, et al., 2013	Research Study
Cramer, et al., 2011	Literature Review
Das, Padakannaya, Pugh, & Singh, 2011	Research Study
Eberhard-Moscicka, et al., 2015	Research Study
Eicher & Gruen, 2013	Literature Review
Fawcett, & Nicolson, 2007	Theoretical work
Fumiko, et al., 2010	Research Study
Griffiths, & Stuart, 2013	Literature Review
Grube, et al., 2014	Research Study
Hruby, & Goswami, 2011	Literature Review
Keller, & Just, 2009	Research Study
Krafnick, Flowers, Napoliello, & Eden., 2012	Research Study
Landi, et al., 2013	Literature Review
Lovio, et al., 2012	Research Study
Maurer, et al., 2011	Research Study
Menghini, et al., 2010	Research Study
Meyler, et al., 2008	Research Study
Pammer, 2013	Literature Review
Raschle, et al., 2012	Research Study
Richlan, Kronbichler, & Wimmer, 2011	Research Study
Strehlow et al., 2006	Research Study
Temple, et al., 2003	Research Study

Vandermosten, Boets, Wouters, Ghesquiere, 2012	Literature Review
Vellutino, Fletcher, Snowling, Scanlon, 2004	Literature Review
Waldie, et al., 2013	Research Study
Willis, 2009	Literature Review
Wimmer, et al., 2010	Research Study
Yamada, et al., 2011	Research Study
Ylinen & Kujala, 2015	Literature Review

Table 2

Authors	Research Design	Participants	Data Sources	Findings
Barquero, Davis, and Cutting, 2014	Mixed Methods	Eight experiments were included for quantitative analysis, with a total of 173 dyslexic participants and 90 activation foci.	Qualitative: 22 studies that met criteria for inclusion in the descriptive literature review Quantitative: fMIR studies of experiments that contrasted activation increases from pre-intervention scans vs post intervention scans	Qualitative finding: Individuals with reading disabilities showed under activation in brain areas of associated with the normal processing of reading, led to relative increases in these same areas after remediation. [described as “normalization” through remediation] Some studies showed that individuals did not normalize but compensated by activating unique areas of the brain. Quantitative findings: of pooling 8 study results of fMRI data pre vs post intervention showed an increased activation in 5 distinct areas of the brain following intervention at the activation thresholds chosen for the study.
Brem, et al.,2009	Quantitative	32 right handed kindergarteners 16 of which identified as a	Three measurements over time using both ERP and fMRI to characterize activation	Longitudinal study of pre-reading kindergarteners. Found that print

		group to have fMRI	of the Visual Word Form Area by a grapheme-phoneme correspondence game (Grapho- Game) vs the same measurements while controls played a number game (NC).	tuning in the VWFS emerges rapidly as children learn the grapheme phoneme correspondences. VWFS critical role is storing these grapheme – phoneme correspondences. The VWFS central role as the source of phonological decoding in developing readers explains in part . why the under activation in this area impacts dyslexic readers.
Costanzo, et al., 2013	Quantitative	10 dyslexic adults	Measures of Reading accuracy (number of errors) and speed (onset reaction times-(RTs)- for word and non-word reading; number of syllables read in the text per second-syll/sec were calculated under control and treatment conditions. Treatment was high frequency repetitive transcranial magnetic stimulation (hf-rTMS) over areas that are underactive in dyslexics during reading. Other brain areas were stimulated in tests as well on the same subjects to establish a site specific effect control	The study showed that hf-rTMS was effective in improving the reading accuracy and speed of dyslexics, and that the effect is strictly task-related and site-specific. Results could suggest new treatment perspectives for dyslexia.
Das, Padakannaya,		40 participants matched in age,	Fluency data. Reaction times and activation	Simultaneous exposure to reading

Pugh, & Singh, 2011		handedness and socioeconomic status: 14 simultaneous and 10 sequential Hindi–English bilingual readers, 9 monolingual Hindi, and 7 monolingual English readers.	patterns (via fMRI) of monolingual English and Hindi readers were compared to two groups of adult biliterates: simultaneous who had learned both languages by age 5, and sequential having learned Hindi at age 5 and English at age 10.	distinct orthographies produces an orthography specific plasticity that persists into adulthood. Confirms that opaque orthographies tend to activate the semantically tuned dorsal and regular orthographies tend to activate phonological decoding pathways
Eberhard-Moscicka, 2015	Qualitative	68 monolingual German first grade students	MEG (EEG potentials) N1 (print tuning) ERP for various literacy activities compared to controls	Print Tuning developed in first year of reading instruction. Related to word reading, No lexicality effect for kindergarten children. Individual effects related to the development of word reading fluency and semantic knowledge
Fumiko, et. al. 2010	Qualitative	25 children with dyslexia vs 20 children with normal reading characteristics.	2.5 yr. Longitudinal study: Behavioral measures ability and reading achievement. DTI an fMRI scans of individuals brains performing reading tasks.	The study attempts to predict if DTI and fMRI measurements could predict future long term gains in individuals with Dyslexia as compared to common behavioral measures. Results indicate: 1. No behavioral measures including the widely used and standardized tests of reading and language predicted future reading gains in dyslexia. 2. White

				matter organization measured by DTI was a strong indicator of future gains. 3. A multivariate analysis of both phonological activation and connectivity could predict which children with dyslexia would make significant gains with 90% accuracy. Brain measures that predict future behavioral outcomes (neuroprognosis) may be more accurate, than available behavioral measures
Grube et.al. 2014	Quantitative	28 individuals with dyslexic traits (DT) compared to 178 individuals of the same age (11 years old) but with typical language and reading development (TD)	Standardized testing of intelligence and reading proficiency. Measures of auditory processing including pitch modulation timing and rhythm	The study sought to determine if the correlation between auditory and language skills were consistent between the different populations. The DT group showed deficiencies in language, but not on the auditory measures of pitch, time, rhythm and timbre. (Modulation). The data supported the notion that fundamental nature between the correlation between auditory and language skills differs for the two populations studied. The data did not support the

				hypothesis that dyslexia is caused by deficits in auditory processing. Results indicate that more work needs to be done to define appropriate strategies to use with DT populations and may indicate the musical training could benefit this population.
Keller & Just, 2009	Quantitative	47 dyslexic readers: 35 of these individual subjected to 100 hours of intervention (word level decoding skills) over a 6 months period, the other 12 controls received only regular class instruction.	Measurements of both ability and achievement in reading with DTI scans for FA (white matter connectivity measure) before and after 100 hours of intervention period as compared to controls.	A behavioral intervention brought about a positive change in white matter tracts in the brain: Increases in the behavioral measures of reading correlated with a beginning low white matter connectivity measure (FA) in dyslexic readers, and a corresponding increases in this values after those individuals received word decoding intervention. Results suggest that intervention led to increased myelination of white matter tracts interconnecting processing nodes in the brain circuits involved in reading.
Krafnick, Flowers, Napoliello, &	Quantitative	11 dyslexic children. 9 male	Standardized measures of reading achievement, and MRI voxel based	Longitudinal study examining GMV changes as a result of

Eden., 2011		and 2 female	measurements of Grey Matter Volume (GMV) in the brains of the test subjects: before intervention began, after 8 weeks of intervention, and again after an 8 week "null period" during which no intervention was provided. The intervention focused on mental imagery, articulation, tracing of letters, groups of letters and words.	reading intervention. Subjects made significant gains in reading measures after the 8 weeks of intervention. GVM measurements increased the 8 week training period, However no increases were observed during the null period which served as a control.
Lovio et. Al., 2012	Quantitative	31 monolingual 6 year olds with developmental dyslexia	Behavioral measures of reading skills and measurement of Event Related Potentials common to effective reading	Significant improvement in both behavioral and neurological measures vs controls for a test group receiving only 3 hours of a computer bases sound discrimination intervention (grapho game) provided in short sessions over 3 week period..
Maurer, et.al. 2011		13 Children with dyslexia, 19 control children with normal reading abilities	Measures of reading ability and skills. EEG measures of ERPs associated with print tuning, and fMRI scans of children while they attempted to discover a match in strings of symbols, nonsense words and words.	Longitudinal study examining what happens to the print tuning deficit discovered in dyslexic children in 2nd grade as they mature relative to controls. Characterized that change with fMRI scans. Results: Robust print tuning deficit in dyslexic children disappeared

				by 5th grade indicating that its presence was a developmental delay. fMRI indicated reduced specific activation bilaterally in temporal areas Dyslexic 5th graders showed more bilateral activation of VWFA than controls confirming the findings of others: Initially deficits in print tuning play a major role in the early reading performance, but by 5th grade, they had developed print tuning and their deficits remained in the visual word form area relative to controls. Demonstrates a plasticity in the traits for dyslexia to account for in theory and age appropriate training.
Menghini et.al., 2010	Quantitative	125 children and adolescents: 60 with developmental dyslexia and 65 normal reading individuals. The two groups age matched with ages ranging from 7-17 years old	Tests of ability and achievement, screens for ADHD, phonological ability and visual processing, selective and sustained attention, implicit learning, and executive function	Results document deficits in the dyslexic group in both phonological and non-phonological skills. In the dyslexic group 23.3% of the unique variance from controls on word reading was due to non-phonological deficits, compared to

				19.3 % of unique variance on non-word reading tests due to non-phonological deficits. Conclusions: Dyslexia is a multifactorial deficit not limited to the linguistic brain, a number of cortical systems are involved. Early diagnosis and intervention of all compromised cognitive functions essential to assure positive outcomes.
Meyler et.al, 2008		5th graders: 10 good readers and 18 poor readers defined by behavioral measures	fMRI scans of brains during a sentence comprehension task at points: prior to remediation, after 100 hours of intensive instruction, and 1 year after the instruction ended.	Prior to instruction, the poor readers had significantly less activation than good readers bilaterally in the parietal cortex, immediately after instruction, poor readers made substantial gains in reading ability, and demonstrated significantly increased activation in the left hemisphere Activation in these regions continued to increase among poor readers 1 year post-remediation, resulting in a normalization of the activation. Areas of over activation also found among poor readers in the medial

				frontal cortex, possibly indicating a more effortful and attentional-guided reading strategies.
Raschle et.al., 2012	Quantitative	36 preschool children: 18 with a family history of dyslexia (FHD+), and 18 children from families with no history of dyslexia (FHD-)	Both behavioral measures of phonogical processing and fMRI measurements of children preforming phonological tasks	Structural and functional characteristics common to developmental dyslexia are present and measureable prior to beginning to learn to read, showing that these characteristics are innate and not due to reading failure. No compensatory processing in frontal or LH areas were noted in these young individuals indicating that these areas are recruited as a result of reading failure.
Richlan Kronbichler, & Wimmer, 2011	Quantitative	337 dyslexic children ages 9 to 11 years old 271 dyslexic adults ages 18-30 years old	9 fMRI studies dyslexic children during reading tasks (ages 9-11), and 9 fMRI studies of dyslexic adults during reading tasks (ages 18-30)	Addresses the question of whether dyslexia progresses from a phonological decoding deficit in the ventral Occipital-Temporal (OT) circuit, to a visual orthographic deficit in the dorsal Parietal Temporal (PT) processing route. [Normal readers rely initially on OT phonological route to decode words and

				progress to primarily a PT orthographic word-form recognition at around age 7] Results did not demonstrate this trend. Authors feel is was caused by a lack of pseudo-word decoding tasks in those studies that failed to show an OT under activation. Studies did show that both the adults and the children had deficits in orthographic parietal temporal processing route. .
Strehlow, et al., 2006	Quantitative	44 dyslexic 8 year old German speaking students	Behavioral measures of acoustic and phoneme processing along with standard measures of reading, spelling abilities and achievement.	Longitudinal study looking at the long term effects of Fast ForWord intervention on reading and spelling Found no difference in reading and spelling ability attributed to Fast ForWord training as compared to controls after 4 weeks of training and again after 6 months. However measures of sound and phonemic processing did show improvements.
Temple et.al., 2003	Quantitative	20 dyslexic children, ages 8-12 years old	fMRI scans of brains during phonological processing, before and after a remediation program focused on	Behaviorally, training improved oral language and reading performance. Physiologically,

			temporal auditory processing and oral language skills	children with dyslexia showed increased activity in multiple brain areas. Increases occurred in left temporal-parietal cortex and left inferior frontal gyrus, bringing brain activation in these regions closer to that seen in normal-reading children.
Vandermosten et.al., 2012	Mixed Methods		18 DTI-studies that related FA to dyslexia and reading	A lower FA in a left temporal parietal region in subjects with dyslexia as compared to typical readers. [FA is generally interpreted as a quantitative biomarker of white matter integrity]
Waldie et. al., 2013	Quantitative	12 adults with dyslexia and 16 controls matched for IQ.	Standardized testing fMRI scans of brains on reading tasks. LLI or lateralization index	Dyslexics show a general right hand lateralization. Research pointed out that more needs to be understood about Right brain word reading compensation, is this compensatory or inhibitory as an atypical reading neurology. Right posterior over activity during reading may be a biological marker for dyslexia
Wimmer et.al., 2010	Quantitative	20 German dyslexic readers	Measures of ability and achievement including	Results indicated that dyslexics preformed

		(19 male, 1 female) and 19 German typical readers (17 male, and 2 female) Groups were age matched.	IQ, both text and sentence reading fluency, vocabulary, Rapid Autonomic Naming (RAN). fMRI scans of participants performing tasks that were either whole word (lexical), phonological in nature or use both routes (pseudo-homophones).	slower than controls on all tests however accuracy was high for both groups. In scanner images indicated that both groups selected a sub-lexical phonological route to word meaning for unfamiliar words and letter strings, and a lexical whole word approach for recognizable words. Dyslexics under-activated in whole word tasks suggests an overall different organization of reading processes.
Yamada et.al., 2011	Quantitative	14 elementary students: 7 on-track (OT), and 7 at risk (AR) for reading problems	fMRI scans of individual on letter tasks: DIBELS initial sound fluency and letter naming fluency screening	Distinct processing differences developed between AR and OT indicating compensatory recruitment (bilateral) TP, and anterior. Versus left lateralization. Postulated developmental norm suggested: start bilateral and specializing to left lateral dorsal posterior activation.
Ylinen & Kujala, 2015	Mixed		17 studies of auditory or phonological interventions on brain function via fMRI using contrast scans.	Phonological training led to increased normalized activation of previously hypoactive inferior frontal and temporal

				occipital processing areas in individuals with Dyslexia. A combination of behavioral and brain measures has the potential to deepen our understanding of language and reading deficits and enable the design of interventions that address core processing problems

3.0 Summary of Findings

Language First: Reading Maps Onto Existing Language Network.

Language develops first. Important to note is that the ability to understand and speak a language is an inherent ability with related components hardwired into the brains neuronal architecture. This language equipment is there at birth in the infant's brain, and develops as the child's brain grows rapidly in the first 3 years of life. Researchers howed that even as early as 4 months old the brain of an infant has developed a distinct network to process the sounds of language syllables in the left hemisphere as opposed to where it processes all other sounds. (Sousa, 2005) This characterization of left sided specialization (left lateralization) in the brain for both language and reading in typical reading individuals appears in many of the studies I reviewed. These researchers have also noted a distinct lack of left sided activation in the brains of individuals with dyslexia (Temple, et al., 2003; Barquero, Davis & Cutting, 2014; Meyler, et al., 2008; Yenlin & Kujala, 2015; Wimmer, et al., 2010)

When we learn language we respond spontaneously to the exposure to our native language, to build up in our brains both a "phonological lexicon" of the sound forms for words that is interconnected with a "semantic lexicon" of word meanings in our brain. I use the word "spontaneous" to denote that this process does not require specific instruction or training only timely exposure to native language. The next hierarchy in language learning and the last to develop are the rules and patterns of how we put together our words into the sentence and phrase patterns of our language, the syntax of speech (Wolf, 2007).

Long before neuroimaging, specific areas of the brain critical to processing language were identified in the left hemisphere of individuals that had damage or lesions to these specific areas of the Brain.

Broca’s area located in the temple in the frontal lobe of the brain called the the left inferior frontal gyrus. It is a critical language center involved in both spoken language and phonological processing. Individuals who have damage in Broca’s area can understand speech, but lose the ability to access their mental lexicon to speak (expressive aphasia).

Werneke’s area just posterior to Broca’s includes the angular gyrus in the left superior temporal cortex and parietal lobe of the brain. Werneke’s area is critical to understanding the syntax of spoken language. This area is about the size of a half dollar and is located just above the left ear. Individuals with damage to this area cannot make sense out of words they speak or hear. They can articulate clearly but what they speak is meaning less (receptive aphasia). More recent research with neuroimaging shows that Broca’s area is activated when processing vocabulary, syntax and the rules of Grammar (Dehane, 2009; Landi, et al., 2013).

Imaging of Wernike’s area indicates that it is more intricately and widely interconnected with other parts of the brain in comparison to the corresponding area in the right hemisp*here. Wernikes area operates independent of consciousness to establish and recognize patterns that are fed to it either via a visual or auditory interconnection, processing the sense and meaning of language (Souza, 2009; Dehane, 2009; Wolf, 2007).

Learning to read is a skill that is mapped onto these and many other components of the existing information processing pathway and structures that enable spoken language. Thus it is important to understand that deficits in language will impact reading ability (Lovio et al.,2012; Grube, et al., 2014). Many individuals with reading disorders upon close scrutiny have atypical features to their early or current language processing (Grube et al., 2014; Lovio et al., 2012). These atypical features could be one way to establish early diagnosis of dyslexia to begin an early intervention (Grube, et al., 2014,; Wolf, 2007; Lovio et al., 2012).

-Learning to Read: Establishing, and Interconnecting the Orthographic lexicon

Many of the Authors discuss how learning to read requires specific instruction and training to create a third lexicon, “the orthographic form”, or written form of a given child’s language. This orthographic lexicon is culturally dependent, and its symbolic representation (writing system) varies considerably between cultures. (Waldie, et al., 2013)

In alphabetic or phonologically transparent writing systems, there is a consistency of phoneme to grapheme rules: An arbitrary group of symbols (graphemes) code consistently for the speech sound parts of words (phonemes). Another term for this is a “transparent orthography” and language examples include Spanish, German, Hindi and Italian (Das, et al., 2011). In contrast other cultural forms of writing such as the Kanji Japanese form, have characters that code for a particular word, or word root and are not based on phonology (Dehaney, 2009). English uses a mix of both forms to represent the words in its spoken language.

What is important to note is that no matter the cultural orthography, there are distinct rules that apply and it is the internalization and automatization in neural networks of these patterns and rules in the brain that encode our orthographic lexicon. It is the development of this orthographic lexicon that allows interconnection in the brain between our already developed language system (semantic and phonological lexicon) that allows us to find meaning in written text (Vandermosten, et al., 2012).

A Dual Route to Reading and its Relevance to Dyslexia

Many authors discussed a dual route to reading in which proficient readers make use of two parallel, dual confirm, processing circuits: a phonological ventral brain route specialized at decoding of words, alongside a semantic whole word recognition dorsal brain route. (Das et al.,2011, Wolf, 2007, Dehane, 2009 Richlan, Kronbichler &Wimmer, 2011). It has been suggested that these two routes operate simultaneously and produce a double confirmation of word recognition. Whole word recognition is a faster approach and is used with familiar, frequently used words whereas the decoding of words is a two part process in which the phonemes must be recognized, associated with their corresponding sounds, and processed sequentially in the auditory portion of the temporal lobe. These two typical processing circuits have been characterized through imaging studies (Waldie, et al., 2013; Das, et al., 2011, Richlan, Kronbichler & Wimmer, et al. 2011; Maurer, et al. 2011) These researchers have also helped "tease out" the particulars of the deficits involved in Dyslexia and how the disorder develops over time. These studies looked at fMRI scans of the brain while varying the transparency of the orthography used in reading tasks. This is done both by studying monolingual and bilingual subjects from different orthographic transparencies (Das et al., 2011; Wimmer, et al., 2010), or varying the tasks between lexical whole word recognition and phonological tasks in subjects from the same culture. (Richlan, Kronbichler, & Wimmer, 2011; Maurer, et al., 2011; Menghini, et al., 2010; Brem, et al., 2009). These studies tended to show that dyslexia presents initially as a phonological deficit, and progresses to a semantic word recognition deficit. There is a high degree of plasticity involved in the brains response to varying the transparency of the orthography learned (Das, et al., 2011).

Both of the dual route pathways characterized used a processing node in the left ventral Occipital Temporal lobe that has become known as the visual word form area (VWFA). fMRI and MEG studies show the activation of this area during reading tasks in typical readers across cultures and orthographies. Studies have indicated that this area is the grapheme to phoneme recognition point (Brem, et al. 2009; Maurer, et al., 2009; .Eberhard Moscickay, et al., 2015). EEG studies of beginning readers show that as kindergarten students begin to display the grapheme to phoneme correspondence, a characteristic "print tuning" ERP is generated at the VWFA. These studies indicate that the normal development of reading networks in the brain begin bilaterally and then specialize to the left hemisphere and especially the VWFA as print-sound correspondence is learned.

Eberhard-Moscickay, et al. in a study with typical readers, showed that the VWFA was activated in whole word recognition as well. He studied the responses to children reading letters and whole words at different ages. He found that older readers would produce an ERP during whole word reading tasks.

Whereas younger kindergarten age children showed no such “lexical effect” (Eberhard-Moscicka, et al., 2013).

Children with dyslexia often fail to produce this ERP until as late as 5th grade indicating a developmental delay in their activation of the VWFA compared to typical readers (Brem, et al., 2009, Maurer, et al 2011).

Researchers who conducted longitudinal studies of print tuning in dyslexics demonstrate a plasticity in the way these individuals attempt to process written material. These changes in the character of the disorder should be accounted for in both research on dyslexia and the selection of appropriate interventions to target an individual’s core problems (Yenlin & Kujala, 2015; Richlan, Kronbichler, & Wimmer, 2011; Maurer, et al., 2011; Grube et al., 2014).

A Brain Plasticity Perspective in Interventions Used With Dyslexia

A number of authors discussed remedial interventions in the context of brain plasticity, the brains ability to adapt and reorganize neural pathways in response to new experiences and learning (Temple, et al., 2003; Das, et al., 2011; Lovio et al., 2012; Cramer, et al., 2011; Waldie, et al.,2013; Maurer, et al., 2011; Pammer, 2013; Lovio, et al., 2013). These authors point to learning to read as a prime example of brain plasticity in which the brain adapts reorganizes and recruits its resources in response to learning.

There are initial differences in their brains of children with dyslexia before exposure to the classroom experience that acts as a stimulus to neuroplasticity. These initial differences can be determined using neurological measures. Examining young children from families with a history of dyslexia with fMRI, DTI, MEG and EEG (Wimmer, et al., 2010; Lovio, et al., 2013; Raschle et al., 2012) specific diagnostic characteristics were suggested that would allow up to 90% accuracy in the early identification of children that will suffer the disorder (Brem, et al., 2009; Fumiko, et al., 2010).

Neuroplastic changes due to intervention are physical and can be measured. DTI was used to show increases in connectivity in the white matter of dyslexic children after intervention (Keller, & Just, 2009). Krafnic, et al. in a careful study of gray matter volume (GVM) in children with dyslexia, demonstrated that GMV increased significantly after intervention compared to a “null period” during which no intervention was provided (Krafnic et al., 2012).

Authors have pointed out that neuroplasticity does not always have a positive effect on behavior (Cramer, et al., 2011; Pammer, 2013) Neuronal recycling in the reading process, mentioned in my introduction, does not proceed in the same way in each individual. As Maryanne Wolf suggests, if one of the systems recruited to perform reading in an individual is atypical from the start, that individuals reading processing may be atypical (Wolf, 2009).

Dyslexia’s Response to Intervention: Normalization or Compensation

Time and again in imaging studies of individuals with dyslexia compared to typical reading controls, a distinct under activation (hypo activation) of the left hemisphere language areas and VWFA is found. (Temple, et al., 2002; Yamada, et al., 2011; Ylinen, & Kujala, 2015; Barquero, Davis & Cutting, 2014; Waldie, et al., 2013; Keller & Just, 2009) These same researcher also showed that some individuals with dyslexia c*ompensate* for their left hypo activation in reading by recruiting more areas in their frontal lobes and right hemisphere of their brain to accomplish reading while others *normalize* their processing to the typical neural network in the left hemisphere used by their proficient reading peers.

Part of the nature of the disorder of dyslexia is that some children will respond to intervention and become proficient readers, but many others continue to struggle into and through adulthood with poor reading skills (Pammer, 2013; Ylinen & Kujala, 2015). What in their initial makeup or plastic response is making the difference for some, and not for others? Yenlin and Kujala have suggested, that the remedial intervention sometimes causes compensatory change to achieve a task and improve a behavior to some degree, but not compete in effectiveness with the optimal change that could have occurred, ie normalization (Yenlin & Kujala, 2015)?

Interventions Should Promote Normalization

The central challenge of interventions intended to create neuro plastic change in brains of dyslexic readers is how to the target plasticity to a given brain system known to be the source of the deficit (Temple, et al., 2003, Pammer, 2013). Current Imaging intervention research for dyslexia tends to focus on phonological and auditory deficits thought to be the most common deficit in an often times multi-faceted disability (Fumiko, et al., 2010, Menghini, et al., 2010)

Some authors have shown that specific phonological training, to improve temporal acoustical skills has improved behavioral measures of reading performance in children with dyslexia. The improvement was shown to accompany a plastic change to their brain processing to more approximate that of typical reading peers (Temple, et al., 2003. This training used nonlinguistic and acoustically modified linguistic speech (rapid frequency transitions in speech are slowed and amplified) incorporated into a computer game called “Fast ForWord”.

However other studies carefully controlling for intervention type have not been able to show that this specific temporal auditory training leads to improvements in behavioral measures of reading in comparison to a number of other phonological interventions (Strehlow, et al., 2006;). A recent study by Grube et al. showed that a population of dyslexic children did process auditory information distinctly differently from typical reading peers, but the results did not support the hypothesis that dyslexia is caused by deficits in temporal auditory processing (Grube, 2014).

Lovio in a study of 31 children with dyslexia showed significant improvements in both behavioral and neurological measures of letter sound discrimination after as little as 30 hours of computer based reading intervention called the “Grapho Game” that works on letter sound correspondence.

Two authors attempted to address the low sample size critique of many Neuroimaging studies. These two studies lumped together a number of fMRI studies with results that contrasted brain scans before, and after intervention to look for commonalities. Ylinen and Kujala combined the results of 17 imaging studies of both phonological and auditory intervention with dyslexic children and found that results indicated a majority of individuals normalized brain function of previously hypoactive brain areas (Ylinen & Kujala, 2015). Barquero et al. combined the results of 8 similar studies and found similar results. Both these authors combined different age groups and readers of different orthographies and both studies had children who also did not show normalization to treatment but compensation by recruiting right hemisphere and frontal areas of the brain to accomplish reading tasks (2014).

Recent technology advances in fMRI and MEG may allow researchers to vary remedial intervention in real time, enabling a more targeted, normalizing brain activation (Cramer et al., 2011). This type of study some argue will require a new discipline “Pedagogical Neuroscience”. One in which neurological imaging and tests would be used to evaluate an individual’s strengths and weaknesses apart from behavioral measures, and design the most appropriate individualized treatment strategies (Fawcet et al., 2007).

Conclusion

Dyslexia is a multifaceted reading disorder that is the result of inherited physical traits that can be linked to atypical brain form and function in individuals with otherwise normal abilities. The disorder is present in many different cultures around the world. Throughout the range of orthographies its prevalence varies depending on the transparency of the orthography. Individuals with dyslexia may have more than one neural deficit contributing to the disability. The atypical brain functioning characteristic to dyslexia may be normalized through remedial interventions, but results are unclear why some individuals normalize and others compensate in ways that lead to a persistence of the disorder.

Neuroimaging is both helping to characterize the disorder and provide a means to study how to induce normalizing plastic change through remedial intervention. Researchers indicate that the disorder can be diagnosed at a pre-reading age and early intervention may prevent developmental delays in print tuning shown to be a common progression to the disorder.

Future neuroimaging studies to discern best practices in effective normalizing interventions should be conducted. They should be latitudinal studies of young pre-reading children who present with the early neuro-diagnostic markers of the disorder. They should use a variety of interventions and measure both behavioral and neurological characteristics of the children in response to each intervention.

Results of latitudinal studies might be used to establish a protocol of scope and sequence of early individualized interventions aimed at stemming the progression of the disorder, and preventing what may be a lifetime of reading disability with accompanying negative effects on self-esteem, motivation and well-being.

References

Barquero, L. A., Davis, N., & Cutting, L. E. (2014). Neuroimaging of reading intervention: a systematic review and activation likelihood estimate meta-analysis. *PloS one*, 9(1), e83668.

Brem S., Bach, S., Kucian, K., Kujala, J.V., Guttorm, T.K., Martin, E., Lyytinen, H., Brandeis, D., & Richardson, U. (2010). Brain sensitivity to print emerges when children learn letter–speech sound correspondences. *PNAS* 2010 107 (17) 7939-7944; published ahead of print April 15, 2010,doi:10.1073/pnas.0904402107

Christmann, C. A., Lachmann, T., & Steinbrink, C. (2015). Evidence for a general auditory processing deficit in developmental dyslexia from a discrimination paradigm using speech versus nonspeech sounds matched in complexity. *J Speech Lang Hear Res*, 58(1), 107-121. doi: 10.1044/2014_JSLHR-L-14-0174.

Costanzo, F., Menghini, D., Caltagirone, C., Oliveri, M., & Vicari, S. (2013). Is high frequency rTMS a new tool in remediating dyslexia? *Clinical Neurophysiology*. October 2013Volume 124, Issue 10, Pages e93–e94 doi: 10.1016/j.clinph.2013.04.139

Cramer, S. C., Sur, M., Dobkin, B. H., O'Brien, C., Sanger, T. D., Trojanowski, J. Q., & Vinogradov, S. (2011). Harnessing neuroplasticity for clinical applications. Brain, 134(6), 1591–1609. doi:10.1093/brain/awr039

Das, T., Padakannaya, P., Pugh, K. R., & Singh, N. C. (2011). Neuroimaging reveals dual routes to reading in simultaneous proficient readers of two orthographies. *NeuroImage*, 54(2), 1476–1487. doi:10.1016/j.neuroimage.2010.09.022

Dehane, S., (2009). Reading in the brain: the science and evolution of a human invention. New York, New York:Viking.

Duke, T. C., (2011). 'Lesbian, gay, bisexual, and transgender youth with disabilities: a meta-synthesis', *Journal of LGBT Youth*, 8: 1, 1-52
DOI: 10.1080/19361653.2011.519181

Eberhard-Moscicka, A. K., Jost, L. B., Raith, M. & Maurer, U. (2015), Neurocognitive mechanisms of learning to read: print tuning in beginning readers related to word-reading fluency and semantics but not phonology. *Developmental Science*, 18: 106–118. doi:10.1111/desc.12189

Eicher, J.D., & Gruen, J.R. (2013), Imaging-Genetics in Dyslexia: Connecting risk genetic variants to brain neuroimaging and ultimately to reading impairments. *Molecular Genetics and Metabolism*. 110(3): 201–212. Published online .doi:10.1016/j.ymgme.2013.07.001

Fawcett, A. J. & Nicolson, R. I. (2007), Dyslexia, learning, and pedagogical neuroscience. *Developmental Medicine & Child Neurology*, 49: 306–311. doi: 10.1111/j.1469-8749.2007.00306.x

Hoeft, F., McCandliss, B. D., Black, Gantman, J. M., Zakerani, N., Hulme, C., Lyytinen, H., Whitfield-Gabrieli, S., Glover, G. H., Reiss, A. L., & Gabrieli, J. D., (2010). Neural systems predicting long-term outcome in dyslexia. *PNAS* 2011 108 (1)361-366; published ahead of print December 20, 2010, doi:10.1073/pnas.1008950108

Griffiths, Y., & Stuart, M., (2013). Reviewing evidence-based practice for pupils with dyslexia and literacy difficulties. *Journal of Research in Reading*, 36(1), 96-116.

Grube, M., Cooper, F.E., Kumar, S., Kelly, T., & Griffiths, T.D., (2014). Exploring the role of auditory analysis in atypical compared to typical language development, *Hearing Research*, Volume 308, February 2014, Pages 129-140, ISSN 0378-5955, http://dx.doi.org/10.1016/j.heares.2013.09.015.

Hruby, G. G. & Goswami, U. (2011). Neuroscience and Reading: A Review for Reading Education Researchers. *Reading Research Quarterly*, 46: 156–172. doi 10.1598/RRQ.46.2.4.

Institute on Disability (2014). Disability compendium. University of New Hampshire: Durham, New Hampshire. As retrieved from: http://disabilitycompendium.org/compendium-statistics/special-education/11-3a-special-education-students-ages-6-21-served-under-idea-part-b-by-select-diagnostic-categories

Keller TA, Just MA, (2009). Altering cortical connectivity: remediation-induced changes in the white matter of poor readers. *Neuron*. 2009; 64(5):624-631. doi:10.1016/j.neuron.2009.10.018.

Krafnick, A. J., Flowers, D. L., Napoliello, E. M., & Eden, G. F., (2011). Gray matter volume changes following reading intervention in dyslexic children. *NeuroImage*, 57(3), 733–741. doi:10.1016/j.neuroimage.2010.10.062

Landi, N., Frost, S. J., Mencl, W. E., Sandak, R., & Pugh, K. R., (2013). Neurobiological bases of reading comprehension: insights from neuroimaging studies of word-level and text-level processing in skilled and impaired readers, *Reading & Writing Quarterly*: Overcoming Learning Difficulties, 29:2, 145-167, DOI: 10.1080/10573569.2013.758566

Lovio, R., Halttunen, A., Lyytinen, H., Näätänen, R., & Kujala,T. (2012). Reading skill and neural processing accuracy improvement after a 3-hour intervention in preschoolers with difficulties in reading-related skills, *Brain Research*, Volume 1448, 11 April 2012, Pages 42-55, ISSN 0006-8993, http://dx.doi.org/10.1016/j.brainres.2012.01.071.

Maurer, U., Schulz, E., Brem, S., van der Mark, S., Bucher, K., Martin, E., Brandeis, D., (2011). The development of print tuning in children with dyslexia: Evidence from longitudinal ERP data supported by fMRI, *NeuroImage*, Volume 57, Issue 3, 1 August 2011, Pages 714-722, ISSN 1053-8119, http://dx.doi.org/10.1016/j.neuroimage.2010.10.055.

Menghini, D.,Finzi, A., Benassi, M., Bolzani, R., Facoetti, A., Giovagnoli,S.,Ruffino,M., Vicari, S. (2010). Different underlying neurocognitive deficits in developmental dyslexia: A comparative study *Neuropsychologia*, Volume 48, Issue 4, Pages 863-872

Meyler, A., Keller, T. A., Cherkassky, V. L., Gabrieli, J. D. E., & Just, M. A. (2008). Modifying the Brain Activation of Poor Readers during Sentence Comprehension with Extended Remedial Instruction: A Longitudinal Study of Neuroplasticity. *Neuropsychologia*, 46(10), 2580–2592. doi:10.1016/j.neuropsychologia.2008.03.012

Pammer, K., (2013). "Brain mechanisms and reading remediation: more questions than answers,"*Scientifica*, vol. 2014, Article ID 802741, 9 pages, 2014. doi:10.1155/2014/802741

Raschle NM, Chang M, Gaab N., (2011). Structural brain alterations associated with dyslexia predate reading onset. *Neuroimage*., Aug 1;57(3):742-9. doi: 10.1016/j.neuroimage.2010.09.055. Epub 2010 Sep 25.

Raschle, N. M., Zuk, J., and Gaab, N., (2012). Functional characteristics of developmental dyslexia in left-hemispheric posterior brain regions predate reading onset. *PNAS* 2012 109 (6) 2156-2161; published ahead of print January 23, 2012, doi:10.1073/pnas.1107721109

Richlan F, Kronbichler M, Wimmer H., (2011). Meta-analyzing brain dysfunctions in dyslexic children and adults. *Neuroimage*. Jun 1; 56(3):1735-42. doi: 10.1016/j.neuroimage.2011.02.040. Epub 2011 Feb 19.

Souza D.A. (2005). How the brain leans to read. Thousand Oaks, California: Corwin Press

Strehlow, U., Haffner, J., Bischof, J., Gratzka, V., Parzer, P., & Resch, F. (2006). Does successful training of temporal processing of sound and phoneme stimuli improve reading and spelling?. European child & adolescent psychiatry, 15(1), 19-29.

Temple, E., Deutsch, G. K., Poldrack, R. A., Miller, S. L., Tallal, P., Merzenich, M. M., & Gabrieli, J. D. E. (2003). Neural deficits in children with dyslexia ameliorated by behavioral remediation: Evidence from functional MRI. *Proceedings of the National Academy of Sciences of the United States of America*, 100(5), 2860–2865. doi:10.1073/pnas.0030098100

Vandermosten, M., Boets, B., Wouters,J., Ghesquière,P., (2012). A qualitative and quantitative review of diffusion tensor imaging studies in reading and dyslexia. *Neuroscience & Biobehavioral Reviews*, Volume 36, Issue 6, July 2012, Pages 1532-1552. doi:10.1016/j.neubiorev.2012.04.002

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): what have we learned in the past four decades? .*Journal Of Child Psychology And Psychiatry*, 45(1), 2-40.

Waldie K.E., Haigh C.E., Badzakova-Trajkov G., Buckley J., & Kirk I. J. (2013). Reading the wrong way with the right hemisphere. *Brain Sciences*. 2013; 3(3):1060-1075.

Willis, J.(2009), What brain research suggests for teaching reading strategies. *The Educational Forum*. Vol.73, Issue. 4, 2009. ProQuest Education Journals
pg. 333. As retrieved from:
http://www.tandfonline.com/doi/abs/10.1080/00131720903166861#.VPKYlfnF-Sq

Wimmer, H., Schurz, M., Sturm, D., Richlan, F., Klackl, J., Kronbichler, M., & Ladurner, G. (2010). A dual-route perspective on poor reading in a regular orthography: An fMRI study. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, 46(10), 1284–1298. doi:10.1016/j.cortex.2010.06.004

Wolf, M. (2007). Proust and the squid: the story and science of reading in the brain. New York, New York: Harper Collins

Yamada, Y., Stevens, C., Dow, M., Harn, B., Chard, D. J., & Neville, H. J. (2011). Emergence of the neural network for reading in five-year old beginning readers of different levels of pre-literacy abilities: an fMRI study. *NeuroImage*, 57(3), 704–713. doi:10.1016/j.neuroimage.2010.10.057

Ylinen, S., & Kujala, T., (2015) Neuroscience illuminating the influence of auditory or phonological intervention on language-related deficits. *Frontiers in Psychology*. V6, No. 137, doi: 10.3389/fpsyg.2015.00137},